

Spacing of traps baited with species-specific *Lymantria* pheromones to prevent interference by antagonistic components

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Abstract—In pheromone-based surveys for detecting multiple species of exotic lymantriine moths (Lepidoptera: Noctuidae: Lymantriinae), spacing between traps baited with species-specific pheromone lures must be sufficient to prevent antagonistic effects of heterospecific pheromone on lure attractiveness. Conducting field experiments with the Japanese gypsy moth, *Lymantria dispar japonica* Motschulsky, in northern Honshu, Japan, we first determined which congeneric pheromone components have strong antagonistic effects on attraction of male moths to the conspecific pheromone (7*R*,8*S*)-*cis*-7,8-epoxy-2-methyloctadecane ((+)-disparlure). Since the most antagonistic compounds were pheromone/volatile components from the sympatric nun moth, *L. monacha* (L.), we then conducted experiments with paired traps baited with either a *L. dispar* (L.) pheromone lure ((+)-disparlure (50 µg)) or *L. monacha* pheromone lure (a mixture of (7*R*,8*S*)-*cis*-7,8-epoxyoctadecane ((+)-monachalure (50 µg)), (7*Z*)-2-methyloctadecene (5 µg), and (+)-disparlure (50 µg)). As spacing between paired traps increased (0, 0.5, 2, 7.5, 15, or 30 m), the antagonistic effect of the *L. monacha* lure on the attractiveness of the *L. dispar* lure decreased and finally disappeared. For pheromone-based detection surveys of multiple species of exotic lymantriine moths in North America to be effective, trap spacing of 15 m is recommended.

Résumé—Les inventaires de détection basés sur les phéromones des papillons lymantriidés exotiques (Lepidoptera : Noctuidae : Lymantriidae) nécessitent un espacement suffisant entre les pièges garnis d'appâts à phéromones spécifiques particulières pour éviter les effets antagonistes des hormones hétérospécifiques sur l'attraction des appâts. Dans des expériences de terrain avec la spongieuse japonaise, *Lymantria dispar japonica* Motschulsky, dans le nord du Honshû (Japon), nous avons d'abord déterminé les composantes congénériques qui ont de forts effets antagonistes sur l'attraction des papillons mâles à la phéromone conspécifique (7*R*,8*S*)-*cis*-7,8-époxy-2-méthylodécane ((+)-disparlure). Comme les composés les plus antagonistes sont la phéromone (composantes volatiles) de la nonne, *L. monacha* (L.), une espèce sympatrique, nous avons monté des expériences avec des pièges appariés garnis ou bien de l'appât phéromonal de *L. dispar* (L.) ((+)-disparlure (50 µg)) ou alors de l'appât phéromonal de *L. monacha* (un mélange de (7*R*,8*S*)-

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cis-7,8-époxyoctadécane ((+)-monachalure (50 µg)) de (7Z)-2-méthyl-octadécène (5 µg) et de (+)-disparlure (50 µg). L'effet antagoniste de l'appât de *L. monacha* sur l'attraction de l'appât de *L. dispar* diminue en fonction de la distance entre les pièges appariés (0, 0,5, 2, 7,5, 15, 30 m) pour finalement disparaître. Nous recommandons un espacement de 15 m entre les pièges pour les inventaires de détection basés sur les phéromones d'espèces multiples de papillons lymantriidés exotiques en Amérique du Nord.

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Introduction

Forty percent of the major insect pests in North American forests and agricultural areas are of exotic origin, even though as a group, they constitute just 2% of the insect fauna (Kim and McPherson 1993). The long-standing close taxonomic affinity of plants in Eurasia and North America (Rohig and Ulrich 1991), both of which were once part of the giant Laurasia landmass (Graham 1993), makes insect exchange between the two continents highly successful. With their innate predisposition to immediately synchronize with North American plants (Stoyenoff *et al.* 1994; Niemelä and Mattson 1996) and enter an "enemy-free" space, Eurasian adventives have become the dominant phytophagous insects in their invaded North American niches. For example, the European gypsy moth, *Lymantria dispar dispar* (L.) (Lepidoptera: Noctuidae: Lymantriinae) (Pogue and Schaefer 2007), has become the dominant defoliator in North American oak forests. The enormous economic and ecological costs incurred because of existing exotic insects and continued entry of new ones call for pro-active and remedial management of exotic insects and heightened national and international quarantine efforts. Development of lures and trapping protocols for use in pheromone-based detection surveys, as well as micro-satellite analyses of populations with diverse geographic ranges, will make a significant contribution to preventing the establishment of exotic lymantriine moth pests in North America.

For efficient pheromone-based detection surveys of exotic species of *Lymantria* Hübner, lures for several species should be deployed. There is evidence, however, that components of the pheromone/volatile blend from one species can be antagonistic to that of another (Grant *et al.* 1996; Gries *et al.* 1996, 2009). Thus, for optimal attractiveness, synthetic pheromone lures used in detection surveys require sufficient spacing. On the other hand, unnecessarily wide spacing between lures will increase the costs of detection

surveys. Our objective was to determine the minimum spacing between species-specific pheromone lures that does not interfere with lure attractiveness.

Material and methods

General design of field experiments

Field experiments were conducted at the Iwate University Research Forest (expt. 1) and the Saezuri-no-Sato Bird Sanctuary (expts. 2–5), both near Morioka, Iwate Prefecture, Honshu, Japan (39°45'N, 141°05'E). In all experiments, delta-like traps (Gray *et al.* 1984) coated with adhesive Tanglefoot (Tanglefoot Company, Grand Rapids, Michigan) were baited with a grey sleeve stopper (West Pharmaceutical Services, Lionville, Pennsylvania) impregnated with test chemicals in solution with high-performance liquid chromatography-grade hexane. In experiment 1, traps were hung in randomized complete blocks (replicates; $n = 10$) from vegetation 1.5–2.0 m above ground at 15 m intervals.

In experiments 2–5 ($n = 10$ each), traps were affixed 1.2–1.3 m above ground to green aluminum poles placed at measured distances along a >2 km long forest road. The distance between paired traps (Fig. 1) was 0, 0.5, 2, or 15 m in experiment 2, 7.5 or 15 m in experiment 3, 15 or 30 m in experiment 4, and 7.5, 15, or 30 m in experiment 5. Trap pairs (Fig. 1) were separated by 30 m (expt. 2) or 60 m (expts. 3–5).

All test chemicals were available from our previous research. They were >96% chemically pure, with enantiomeric excess (ee) between 88% and 99.9%. Experiments were conducted between 2001 and 2008 on dates shown in the figures.

Experiments 1–5

Experiment 1 was designed to determine the congeneric pheromone components or non-pheromonal volatiles in pheromone gland extracts from congeneric females that are strongly

Fig. 1. Schematic drawing depicting the spacing between paired delta-like traps and between trap pairs in experiment 2. Trap 1 was baited with synthetic pheromone of *Lymantria dispar* ((7*R*,8*S*)-*cis*-7,8-epoxy-2-methyloctadecane ((+)-disparlure (50 µg)) and trap 2 with synthetic pheromone of *L. monacha* (a mixture of (7*R*,8*S*)-*cis*-7,8-epoxyoctadecane ((+)-monachalure (50 µg), (+)-disparlure (50 µg), and (7*Z*)-2-methyloctadecene (5 µg)). Distances are not shown to scale.

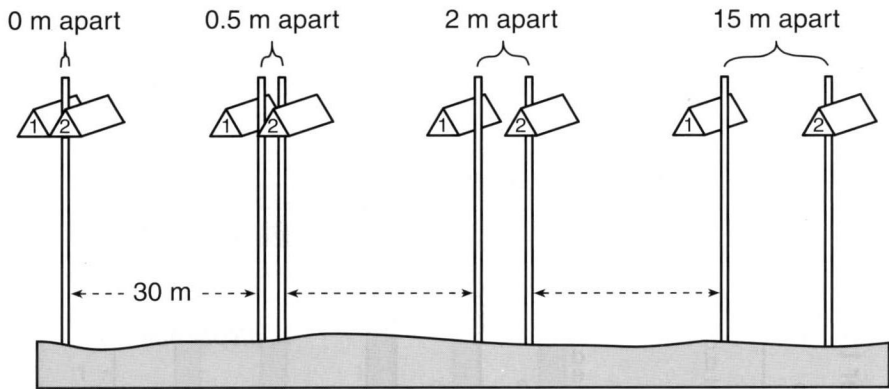


Fig. 2. Numbers (mean + SE) of male *Lymantria dispar japonica* captured in the Iwate University Research Forest (Morioka, Honshu, Japan) in delta-like traps baited with synthetic (+)-disparlure (the pheromone of *L. dispar*) alone or in combination with synthetic pheromone or volatile components identified in pheromone gland extracts and (or) effluvia of female congeners. A different letter above the bar denotes a statistical difference (one-way ANOVA ($F_{9,90} = 36.72$, $P < 0.0001$) followed by the Student–Newman–Keuls test ($\alpha = 0.05$)).

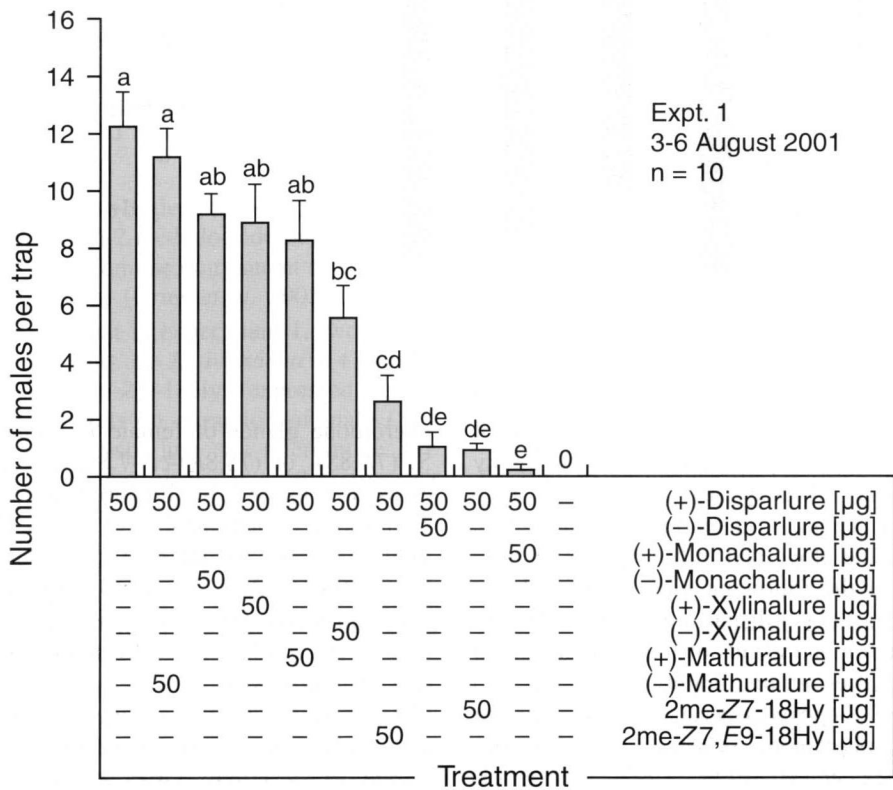
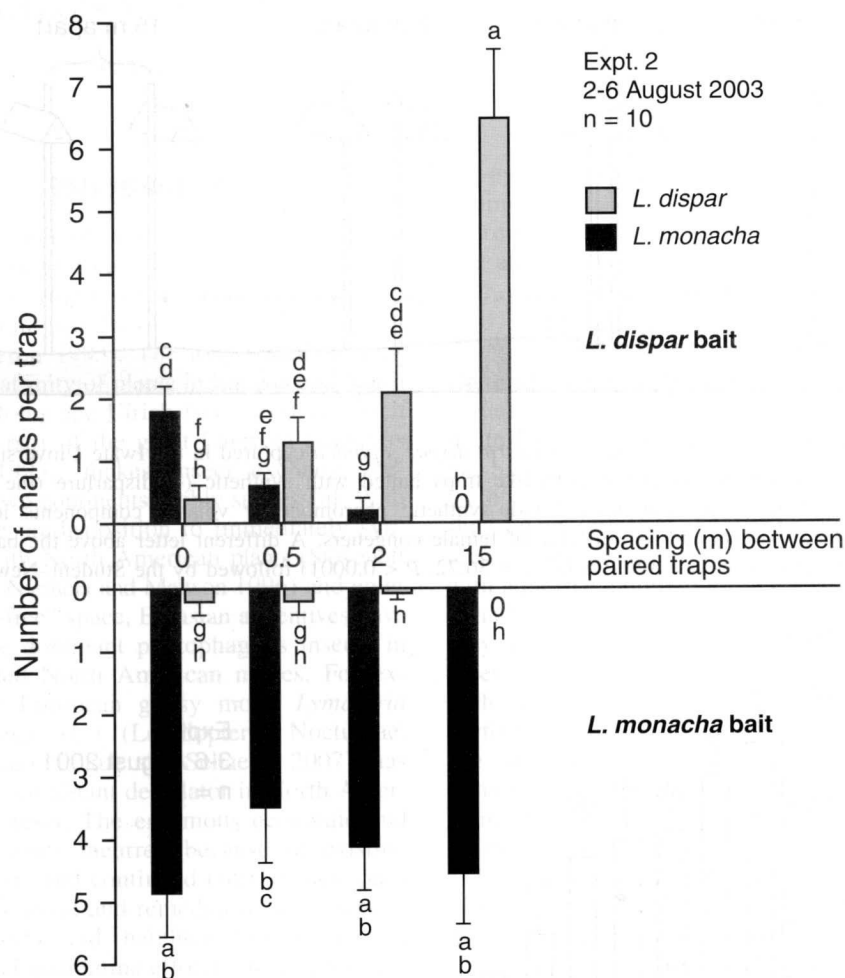


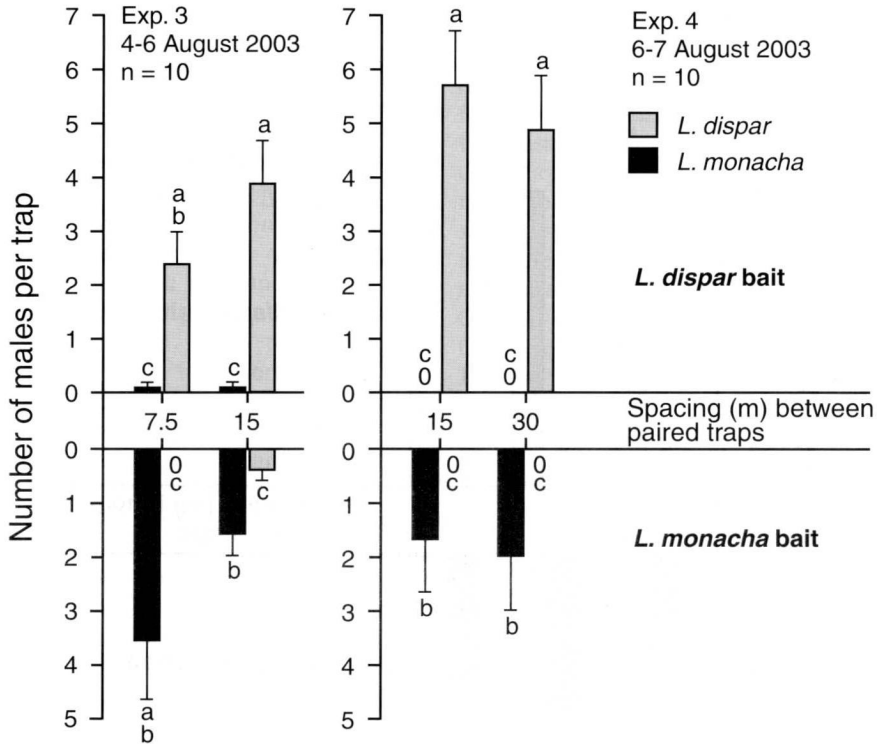
Fig. 3. Numbers (mean \pm SE) of male *Lymantria dispar japonica* and male *L. monacha* captured at the Saezuri-no-Sato Bird Sanctuary (Morioka, Honshu, Japan) in paired delta-like traps (10 replicates) baited with synthetic pheromone of *L. dispar* or *L. monacha* (see Fig. 1). The spacing between paired traps was 30 m. A different letter above the bar denotes a statistical difference (two-way ANOVA ($F_{15,144} = 20.8566$, $P < 0.0001$) followed by least significant means differences Student's *t* test ($\alpha = 0.05$)).



antagonistic to the pheromonal attraction of male *Lymantria dispar japonica* Motschulsky to (7*R*,8*S*)-*cis*-7,8-epoxy-2-methyloctadecane ((+)-disparlure). Thus, (+)-disparlure (50 μ g; >99% ee) was tested alone and in binary combination with one of the following nine compounds (at 50 μ g each): (1) (–)-disparlure (volatile component in pheromone glands of female *L. monacha* (L.)) (G. Gries *et al.*, unpublished data); (2) (7*R*,8*S*)-*cis*-7,8-epoxyoctadecane ((+)-monachalure (>99% ee), pheromone component from *L. monacha*) (Gries *et al.* 1996, 1997, 2001); (3) (7*S*,8*R*)-*cis*-7,8-epoxyoctadecane ((–)-monachalure (>99% ee), predicted volatile component in

pheromone glands of female *L. monacha*); (4, 5) (7*R*,8*S*)- or (7*S*,8*R*)-*cis*-7,8-epoxy-2-methyleicosane ((+)- or (–)-xylinalure (each >99% ee), pheromone components of the Casuarina moth, *L. xylina* Swinhoe) (Gries *et al.* 1999*b*); (6, 7) (9*R*,10*S*,3*Z*,6*Z*)- and (9*S*,10*R*,3*Z*,6*Z*)-*cis*-9,10-epoxynonadecadiene ((+)- or (–)-mathuralure (each >88% ee), pheromone components of *L. mathura* Moore) (Gries *et al.* 1999*a*); (8) (7*Z*)-2-methyloctadecene (2me-7*Z*-18Hy, synergistic pheromone component of *L. monacha* (Grant *et al.* 1996; Gries *et al.* 1996) and *L. fumida* Butler (Schaefer *et al.* 1999), and major pheromone component of *L. serva* (F.)

Fig. 4. Numbers (mean + SE) of male *Lymantria dispar japonica* and male *L. monacha* captured in experiments 3 and 4 (10 replicates each) in a mixed forest in the Saezuri-no-Sato Bird Sanctuary in paired delta-like traps (10 replicates) baited with synthetic pheromone of *L. dispar* or *L. monacha* (see Fig. 1). The spacing between paired traps was 60 m. In each experiment a different letter above the bar denotes a statistical difference (two-way ANOVA (expt. 3: $F_{7,72} = 14.0302$, $P < 0.0001$; expt. 4: $F_{7,72} = 17.7906$, $P < 0.0001$) followed by the least significant means differences Student's *t* test ($\alpha = 0.05$)).



and *L. lucescens* (Butler) (Gries et al. 2002)); and (9) (7Z,9E)-2-methyloctadecadiene (2me-7Z9E-18Hy, pheromone component of *L. bantaziana* Matsumura) (Gries et al. 2005).

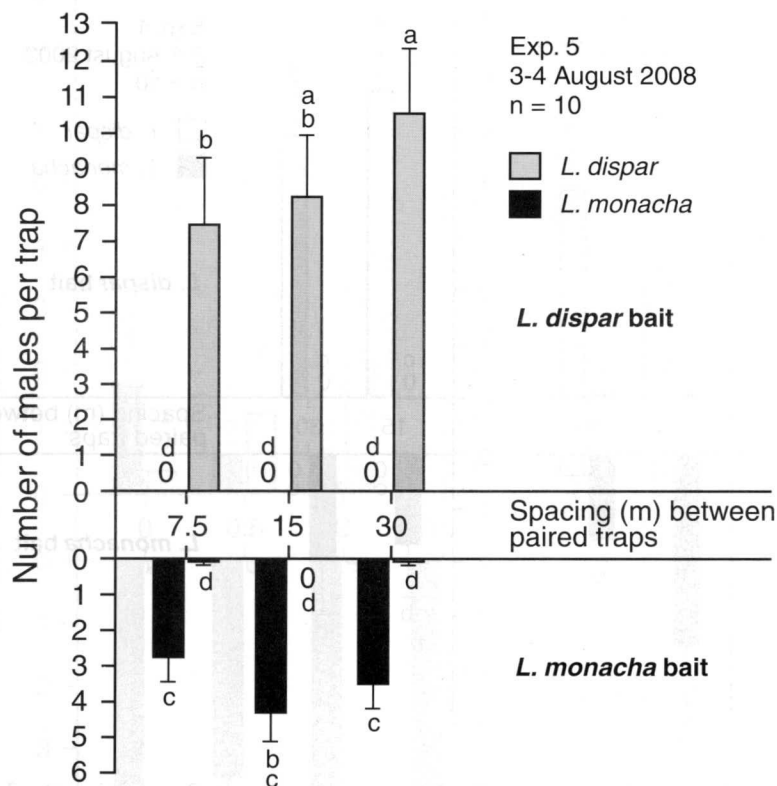
Considering that in experiment 1, two pheromone components of *L. monacha* ((+)-monachalure and 2me-Z7-18Hy) expressed strong antagonistic effects on attraction of male *L. d. japonica* to (+)-disparlure, the pheromone lure for *L. monacha* was selected as the strongest antagonistic lure for determining the minimum distance from the lure for *L. dispar* (L.) at which it would not interfere with the attractiveness of the latter. Thus, experiments 2–4 (each $n = 10$) tested paired traps, each baited with a lure for either male *L. d. japonica* ((+)-disparlure (50 µg)) or male *L. monacha* (a mixture of (+)-monachalure (50 µg), 2me-7Z-18Hy (5 µg), and (+)-disparlure (50 µg)).

In view of the antagonistic effect of the *L. monacha* lure on attraction of male *L. d. japonica* to nearby (0, 0.5, or 2 m) *L. dispar* lures

in experiment 2, experiments 3 and 4 tested paired traps with an intertrap distance of 7.5 or 15 m and 15 or 30 m, respectively. Taking into account that female (European) *L. monacha* produce both (+)- and (–)-disparlure (the latter is not a pheromone component for male *L. monacha* but an antagonist to male *L. d. dispar* and *L. d. japonica*) and that commercial *L. monacha* lures contain racemic compounds, the final experiment (expt. 5) tested paired traps with intertrap distance of 7.5, 15, or 30 m, each trap baited with a lure for either male *L. d. japonica* ((+)-disparlure (50 µg)) or *L. monacha* (a mixture of racemic monachalure (100 µg), 2me-Z7-18Hy (5 µg), and racemic disparlure (100 µg)).

Trap-catch data from all experiments were subjected to transformation ($\log x + 1$) to ensure normal distribution and homogeneity of variance, and were analyzed by one-way ANOVA followed by the Student–Newman–Keuls test ($\alpha = 0.05$; expt. 1) or by two-way

Fig. 5. Numbers (mean \pm SE) of *Lymantria dispar japonica* and male *L. monacha* captured in a mixed forest 25 km west of Morioka in paired delta-like traps (10 replicates) baited with synthetic baits for *L. dispar* ((+)-disparlure (50 μ g)) or *L. monacha* (a mixture of racemic monachalure (100 μ g), racemic disparlure (100 μ g), and (7Z)-2-methyloctadecene (5 μ g)) (see Fig. 1). The spacing between paired traps was 60 m. A different letter above the bar denotes a statistical difference (two-way ANOVA ($F_{11,108} = 29.42$, $P < 0.0001$) followed by the least significant means differences Student's t test ($\alpha = 0.05$)).



ANOVA followed by least significant means differences Student's t test ($\alpha = 0.05$; expts. 2–5) (Zar 1984; SAS Institute Inc. 1988). Zero trap catch data from non-baited-control treatments were not included in analyses.

Results and discussion

In experiment 1 the heterospecific pheromone components (+)-monachalure, 2me-7Z-18Hy, 2me-7Z9E-18Hy, and (–)-xylinalure significantly reduced attraction of male *L. d. japonica* to (+)-disparlure, as did nonpheromonal (–)-disparlure (Fig. 2). Other congeneric pheromone components, including (+)-xylinalure and (+)- and (–)-mathuralure as well as nonpheromonal (–)-monachalure, had no behaviour-modifying effect (Fig. 2).

The response of male *L. d. japonica* resembles that of European male *L. d. dispar*, whose attraction to pheromone is reduced in the presence of (–)-disparlure (Klimetzek *et al.* 1976; Cardé *et al.* 1977; Miller *et al.* 1977; Plimmer *et al.* 1977), 2me-7Z-18Hy (Cardé *et al.* 1973), and (+)- and (–)-monachalure (Gries *et al.* 1996). The strong antagonistic effects of (+)-monachalure and 2me-7Z-18Hy in experiment 1 may be attributed to the fact that these are major and synergistic pheromone components, respectively, for sympatric *L. monacha* (Gries *et al.* 2001) and that 2me-7Z-18Hy is also the major pheromone of sympatric *L. lucescens*³ (Gries *et al.* 2002). The pheromone component (+)-xylinalure for allopatric *L. xylina* may not be recognized by *L. d. japonica*, and the antagonistic effect of (–)-xylinalure (Fig. 2) may be due to its

³*Lymantria lucescens* is found elsewhere on Honshu and is likely present but not yet recorded near Morioka.

resemblance to homologous (–)-disparlure. Similarly, the antagonistic effect of the *L. bantai-zana* pheromone 2me-7Z9E-18Hy (Fig. 2) may be due to its structural similarity to 2me-7Z-18Hy. That the *L. mathura* pheromone components (+) and (–)-mathuralure, singly (Fig. 2) and in combination (Gries *et al.* 2009), had no antagonistic effect on *L. d. japonica* is not understood because (+)-disparlure, in turn, is a behavioural antagonist to pheromonal communication by *L. mathura* (Gries *et al.* 2009).

With three compounds ((+)-monachalure, 2me-7Z-18Hy, and (–)-disparlure) in the sexual communication system of *L. monacha* antagonistic to pheromonal attraction of *L. dispar* (Fig. 2), the *L. monacha* pheromone lure was the obvious choice for exploring the minimum spacing needed between it and the *L. dispar* pheromone lure so as to not interfere with the attractiveness of the latter. In experiment 2, captures of male *L. dispar* in traps baited with the *L. dispar* lure increased significantly with distance (0, 0.5, 2, 15 m) to paired traps baited with the *L. monacha* lure (Fig. 3). In contrast, captures of male *L. monacha* in traps baited with the *L. monacha* lure were not affected by their distance from (+)-disparlure-baited traps. Yet with increasing spacing between paired traps, fewer male *L. monacha* entered the (+)-disparlure-baited trap (Fig. 3).

In experiment 3, similar numbers of male *L. d. japonica* were captured in (+)-disparlure-baited traps irrespective of their distance from paired traps baited with the *L. monacha* lure: 7.5 or 15 m in experiment 3, and 15 or 30 m in experiment 4 (Fig. 4). In the final experiment (expt. 5), captures of male *L. d. japonica* in (+)-disparlure-baited traps did not differ statistically, irrespective of whether the trap was placed 7.5, 15, or 30 m from paired traps baited with a *L. monacha* pheromone lure that emitted racemic monachalure, 2me-Z7-18Hy, and racemic disparlure (Fig. 5).

Our data obtained in experiments 2–5 suggest that >7.5 m spacing between congeneric pheromone baits will suffice to eliminate antagonistic effects that interfere with lure attractiveness. Indeed, the minimal spacing required may range between 2 and 7.5 m (Figs. 3, 5). However, because commercial baits may have higher pheromone loadings and release rates than those tested in our study, and the active range of baits depends on pheromone dose (Baker and Roelofs 1981), >15 m trap spacing appears

advisable in surveys to detect multiple species of exotic lymantriine moths in North America.

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